XVII. *Description of an Escapement for an Astronomical Clock, invented by the late Captain* Henry Kater, *F.R.S. &c., drawn up from his own Memorandums by his Son* Edward Kater, *Esq. Communicated by Sir* J. F. W. Herschel, *Bart., K.H. V.P.R.S. &c.*

Received March 26,—Read April 30, 1840.

In venturing to offer to the attention of the Royal Society the following description of an escapement for an astronomical clock, I beg to premise that I restrict myself almost entirely to the collecting and arranging of my father's own notes respecting it, written at intervals during the many years he was engaged upon it. His last improvement was made very shortly before his death, but from increasing ill health he was unable to pursue the requisite observations for verifying the accuracy of the present plan.

Owing to the numerous memorandums left by my father on this subject, I am fortunately able to give the description of the escapement nearly in his own words, with but little addition beyond some drawings which I have made to elucidate the explanations.

I regret that I have not had an opportunity of trying this escapement myself, but from the great care and attention which my father bestowed upon it, I am induced to believe that it may prove a valuable invention.

The two escapements most usually found in observatories, viz. Graham's dead beat and Mudge's escapement, were objected to by my father, on the ground of the fatal defect common to them as well as to all others hitherto invented, namely, that the impulse communicated to the pendulum is affected by any irregularity with which the impelling power is transmitted through the train.

If the number of wheels and pinions of which the train consists be taken into consideration, it was his opinion, that no excellence of workmanship can ever ensure that equality of ultimate action on the pendulum, which is the great desideratum, and which is necessary to its perfect performance.

In the dead beat escapement, the impulse is given by the teeth of the scape-wheel, pressing and sliding on inclined planes or pallets connected with the pendulum, which thus urges it in the direction of its vibration. The degree of impulse, therefore, communicated to the pendulum, will depend on the force with which the teeth of the scape-wheel press upon the inclined planes, and this will vary according as the moving power is transmitted with more or less freedom through the train.

Mudge's escapement consists of two arms, moving on separate axes, and terminated

by inclined planes or pallets. At the top of each inclined plane is a projecting detent, on which the tooth of the scape-wheel rests, after having, by sliding along the inclined plane, raised the detent through a space equal to the height of the plane.

The pendulum, meeting a wire which projects from the arm, forces the detent from the tooth which rested upon it, carries the arm before it to a certain height, and is pressed by the arm in its descent through a space increased by the height of the inclined plane or pallet, the excess affording the impulse.

Although my father admitted that this escapement performed admirably, he still objected to it, first, because it is dependent upon the train, and consequently a greater or less pressure of the tooth of the scape-wheel upon the detent will oppose a corresponding resistance to the pendulum in unlocking; and secondly, because the beat is scarcely audible. If to remedy this, weight be added to the clock, it will then be liable to trip.

The little success with which attempts to improve the astronomical clock had been attended, my father considered might be accounted for by the circumstance, that attention had been almost exclusively paid to effecting, by means of superior workmanship, a regular transmission of the moving power through the train, instead of merely viewing the train as an assemblage of wheel-work for registering the number of vibrations made by the pendulum; whereas, he conceived that the great object was to discover a mode of communicating equal impulse to the pendulum through some principle, perfect in itself, and not dependent for its success on superior execution.

In the construction of some chronometers, this idea has been partially kept in view, especially in the Remontoir escapements; and in such escapements the train is employed merely to wind up a spring, which is detained in its place by means of a detent. This detent being removed by the balance, the spring is again at liberty to act and give the impulse.

The objection, however, to the Remontoir escapement is, that the balance has to unlock a detent, and thus the delicacy and freedom of motion of that part, the undisturbed action of which should be as much as possible preserved inviolate, is interfered with, and this, my father conceived, was the reason that chronometers with Remontoir escapements proved in some respects less perfect in their performance than those of the usual superior construction, in which the impulse is given directly through the train.

The pendulum of the escapement which I am about to describe merely raises a weight, and is impelled by that weight through an increased space in its descent; it neither unlocks a detent, nor has anything to do with the train; and as the weight raised and the spaces described are constant quantities, this escapement is in the strict meaning of the term one of equal impulse.

I shall now proceed to give the general description of the escapement and its mode of action, together with the precautions necessary to be observed in its construction, which I have collected from the notes left by my father, and as I wrote many of

Fig. 2.

Fig. 4.

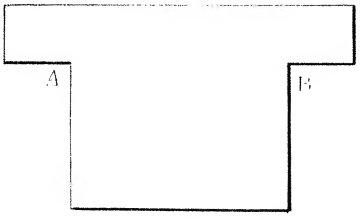
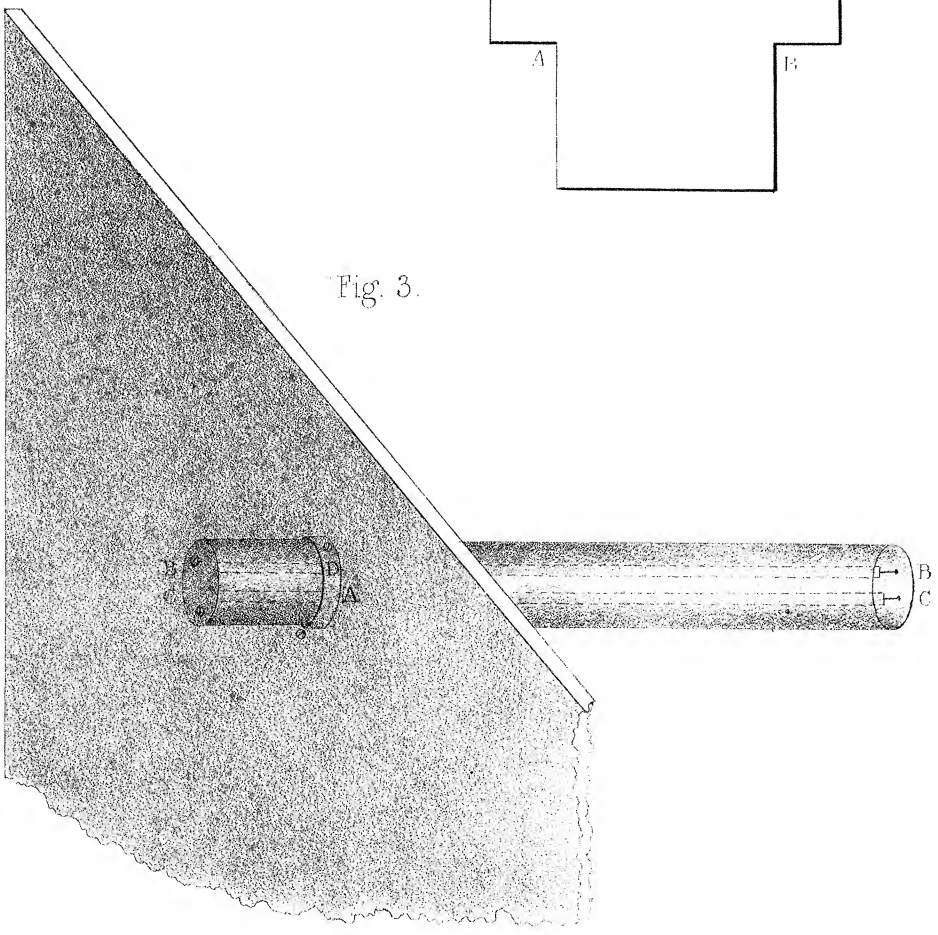


Fig. 3.



them down from his own dictation, and frequently assisted him in many of the experiments, I can give this description as if it came from his own pen. I have added also a more minute account of its various parts, and of their size and weight, which I have lately estimated.

In Plate XI. fig. 1., A represents a piece of brass, which is called from its shape the anchor, to which the detents, *a* and *b*, made of thin plates of agate, are attached. The anchor is supported on an axis passing through its centre of gravity: it is 0·24 inches thick, and weighs about 4031·4 grains. The detents are regulated so as to engage at the proper depth by means of the pins *q*, *r*, having oval or eccentric heads. Two arms, *d e* and *f g*, are supported by two separate axes at *d* and *f*; and at *e* and *g*, two steel pins project at right angles to the arms, between which is the cross-piece of the pendulum, upon which these steel pins act. Two pallets, *h* and *i*, faced with agate, are attached to the arms *k v*, *l*, *w*, and move by the flexibility of their springs at *t* and *x*, which serve merely as joints. The motion of the pallets is limited and regulated by the screws *m* and *n*, which pass through cocks attached to the arms *d e* and *f g*. Two screws, *o* and *p*, are tapped into the arms *d e* and *f g*, and pass through large holes made in the arms carrying the pallets. These screws are intended to act upon the anchor, and raise the detents.

Fig. 1. represents the situation of the different parts of the escapement when the pendulum is descending in the direction indicated by the arrow. On the one side, a tooth of the scape-wheel having elevated the pallet *i* through a space equal to the height of its inclined plane, is resting on its summit. The anchor is pressed upon by the screw *p*, with the weight of the arm *f g*, so as to render any tripping impossible, and the scape-wheel is locked by the detent *a*. As the pendulum advances, the cross-piece meets the projecting wire at *g*, carries forward the arm *f g*, frees the anchor from the pressure of the screw *p*, leaving it free to be acted upon on the other side, and ultimately raises the pallet *i*, by means of the screw *n* meeting its arm. By the time this has been effected, the bottom of the inclined plane of the pallet *h* meets a tooth, and the screw *o* is all but in contact with the anchor. The weight of the pallet *h* is thus taken off from the pendulum, whilst the weight of the arm *d e* continues for a moment to impel it, till the screw comes in contact with the anchor. At this instant a sudden stop, during a small fraction of a second, takes place in the motion of the arm, in consequence of the vis inertiæ arising from the great weight of the anchor. The pendulum, therefore, is no longer rested upon, but having quitted the wire at *e*, the weight of the arm *d e* overcomes the inertia of the anchor, the detent *b* is pressed down, and the scape-wheel being freed, raises the pallet *h*, and rests on the summit by another tooth having come in contact with the detent *b*.

Such is the action of this escapement. Its perfection depends on the action of the arm upon the pendulum being at once checked, and terminated by the vis inertiæ of the anchor, in which case the pendulum quits it, leaving to the arm the work of

unlocking the detent. To calculate with accuracy the time the arm is detained is perhaps impossible, but a sufficient approximation to this may, and has been made, to demonstrate that it cannot overtake the pendulum during the unlocking of the scape-wheel, which is all that is necessary.

This escapement, therefore, is demonstrably one of equal impulse, the impelling power being purely the pressure of the pallet in its descent, through a space equal to the height of its inclined plane.

I shall now give the directions which my father considered might be necessary for the construction of the escapement.

The various parts which compose the escapement are attached to a piece of plate brass, which is afterwards screwed to the back plate of the clock, in such a position as to place the detents in their proper situation with respect to the scape-wheel. The anchor, as already mentioned, 0·24 inch thick, and weighing 4031·4 grains, is made thus heavy in order that its inertia may be sufficient to arrest the descent of the impelling arm, so that, during the raising of the detent, the arm cannot possibly overtake the pendulum. The form of the anchor is sufficiently indicated by the plate. The axis is of steel, and turned with shoulders: it is made to pass through the centre of gravity of the anchor by filing it away when necessary, after the detents are attached to it. The detents are small plates of agate, properly bevelled at the extremity, and fixed in their places by shell-lac. The distance between the faces comprise eight and a half teeth of the scape-wheel, and the chord or distance between the extremities of the detents may be found by multiplying the diameter of the scape-wheel by 0·777. If lines $y\ a$ and $y\ b$ be drawn from the axis of the anchor to the extremity of each detent, and the faces of the detents be produced to a' and b', the angle $y\ bb'$ should be rather less, and the angle $y\ a\ a'$ should be rather more than a right angle; perhaps a difference of five degrees from a right angle may be quite sufficient. The object in this is to give a tendency to the scape-wheel to draw the detents downwards.

The anchor is screwed in its place by means of a cock, which receives one end of the axis, the other end passing into the brass plate.

The distance of the axis of the anchor above the centre of the scape-wheel is found by multiplying the diameter of the scape-wheel by 0·64.

The steel stops, q and r, are rivetted into the brass plate, but not so firmly but that they may be turned by a screw-driver. The upper part of these stops is made either oval or eccentric. They serve to regulate the depth to which the detents are to engage the teeth of the scape-wheel.

The arms $d\ e$ and $f\ g$ are of plate brass. The length of each arm, from the point where it is attached to the axis, in a straight line drawn to the lower end where the steel wire projects, is about 4·8 inches. Each of these arms is attached to an axis by a screw and steady pin, and from the lower end of each arm, a piece of steel wire projects for the purpose of impelling the pendulum.

The axis to which the arm is attached is represented in Plate XII. fig. 2. It is merely a piece of steel wire 3·1 inches long (to prevent shake), having a small plate of brass brazed to it at A, to which the arm is screwed.

The piece for receiving the two axes is represented by B C, fig. 3. It is firmly fastened to the brass plate A, which carries the escapement, by means of screws passing through the piece D, which forms a part of it. The holes for receiving the axes are drilled quite through the ends B and C, and caps of plane brass, carrying planes of agate, are screwed to the ends, and keep the axes in their places, preventing any longitudinal motion. The axes are placed at one diameter of the scape-wheel above the centre.

The pallets are of brass and faced with agate; they are carried by arms terminating in very flexible springs, which serve merely as hinges, and these springs are attached to the arms *d e* and *f g*, Plate XI. fig. 1.; at *v* and *w* the arms project a little beyond the pallets, and rest upon the screws *m* and *n*, which pass through cocks fixed to the arms *d e* and *f g*. The length of the arms carrying the pallets is such, that a tooth of the scape-wheel may rest at the bottom of the one pallet, when another tooth is at the summit of the opposite pallet.

The pallets should be made light, and if it be found necessary to increase the impelling power, it may be done by fixing a pin in the arm carrying the pallet, which pin must pass freely through the impelling arm, and being formed with a shoulder, may be loaded by lodging upon it such small weights as may be necessary.

The steel pins *o* and *p* are tapped into the arms *d e* and *f g*, and pass freely through holes in the arms carrying the pallets. Their position is such, as to allow of their acting upon the anchor at the stops *q* and *r*; all the screws act upon small pieces of agate, let into the brass-work, and they are furnished with nuts to prevent any shake or motion after the adjustments are completed.

The pendulum which is employed with this escapement has a glass cylinder, which holds the mercury used for the compensation, upon the surface of which a circular piece of plate glass floats, to prevent any sudden change of curvature which might arise from the adhesion of the mercury to the sides of the vessel, upon a change of temperature. This cylinder has a projecting rim at top which admits of its being lodged in a sort of iron hoop, formed like a box, with an aperture in the bottom through which the glass cylinder passes, and into which it is cemented. An iron cover screws into this box, having a projecting tube in the centre, to receive a glass tube, which is the rod of the pendulum. The pendulum is suspended by a spring in the usual manner, from a stout cock firmly screwed to the back of the clock-case, and in which all shake is precluded by the pressure of a screw passing through the side of the cock.

The pendulum has a sliding weight on its rod, for the purpose of approximate adjustment, and the final adjustment is effected by small weights placed upon the iron cover.

The cross-piece Z of the pendulum is represented in fig. 1. In consequence of its sides being bevelled, its acting part may be increased by raising it on the rod of the pendulum. The cock which carries the pendulum itself is supported upon a cast-iron bracket, firmly fastened to the clock-case.

The adjustments of the escapement are made in the following manner:

First, the brass plate carrying the whole must be screwed to the back plate of the clock, so that neither of the detents being pressed down, they may first enter within the teeth of the scape-wheel. By this arrangement it will be impossible for the scape-wheel to turn round without encountering one or other of the detents.

The next is by means of the executive stops, to adjust the depth, to which the detents shall engage the teeth of the scape-wheel, and this should not be more than is necessary for secure locking.

A piece of card of the form represented in Plate XII. fig. 4. must be prepared, A B being equal to the upper, or least width of the cross-piece of the pendulum.

The clock must be placed upon a level support, and the card lodged upon the impelling wires of the escapement; a tooth must be made to press against the detents, and the pallet which is on the same side with this detent should be adjusted, by means of its approximate screw, *m* or *n*, so that it shall be quite clear of the tooth of the scape-wheel. The other detent must now engage a tooth, and its pallet be adjusted in like manner. Lastly, the card paper is removed, and the anchor being kept in contact with one of its stops, a tooth pressing against the detent, the pallet on the opposite side will rest with the bottom of its inclined plane upon a tooth of the scape-wheel. The screw *o* or *p*, which is on the same side as this pallet, must now be advanced, until by acting upon the anchor, it just causes the pallet to clear the tooth. This is too much, and the screw must now be withdrawn a little till it is found by trial, that when the bottom of the inclined plane of the pallet meets the tooth of the scape-wheel, the screw is just short of the anchor. The same process must be gone through on the other side, and the adjustments of the escapement will then be completed.

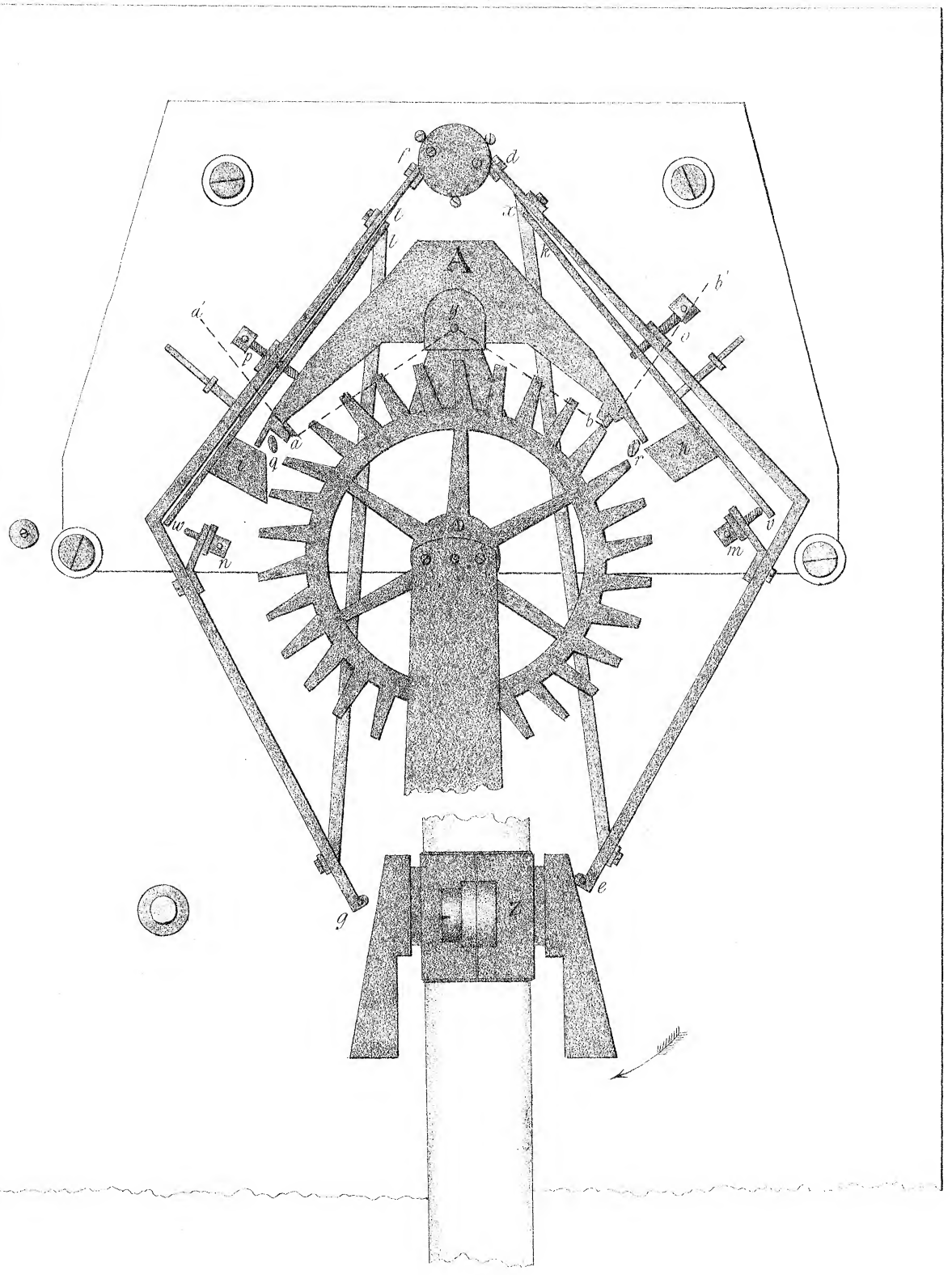
The weight to the clock must be adjusted by trial, so that the scape-wheel shall raise the pallets promptly, but not press with unnecessary force upon the detents.

The plan for fastening the clock-case to the wall is by a single screw passing through its back, a little above the cock which carries the pendulum.

Another similar screw passes through the case into the wall, a little below the ball of the pendulum, and is furnished with a washer. A slit is here cut in the clock-case, at the back, parallel to the horizon, and the clock is put into beat by moving the case as much as may be necessary about the upper screw as a centre, and the clock-case is then firmly fixed by tightening the lower screw. It is scarcely necessary to say, that the clock-case should not touch the floor.

My father never made use of oil in this escapement, as it might, by becoming glutinous, occasion irregular action.

Fig. 1.



F. Baily, del.

J. Basire, Lith.